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"STUDY OF INVENTORY MANAGEMENT IN PHARMACEUTICAL INDUSTRY"

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Abstract: This paper presents a broad overview of inventory management within the pharmaceutical industry. Effective inventory management helps organizations determine what products to order, when to order them, and in what quantities. It involves tracking stock from procurement to final sale, monitoring demand patterns, and adjusting accordingly to ensure adequate availability. While stockouts typically lead to lost sales and reduced profits for most businesses, in the pharmaceutical sector they can result in prolonged illness, fatalities, or even malpractice lawsuits—situations hospital administrators strive to avoid.

Therefore, precise oversight is essential to manage stock levels, monitor expiration dates, and maintain proper storage conditions. Tools such as barcode scanning at receipt, lot tracking for monitoring product movement within the facility, and accurate sales recording make this possible. Regardless of where a transaction takes place, updates to physical inventory must be reflected across the entire system.

Despite numerous theoretical inventory models proposed over the years, many have not been implemented by pharmaceutical organizations due to limited real-world testing. This creates a need to examine the practical relevance and impact of Inventory Theory by validating a simple inventory model in a high-demand hospital setting in India. This paper aims to evaluate the theory, explore its global applications in healthcare institutions, and highlight its advantages.

Keywords: Inventory Control, Pharmaceutical Sector, Supply Chain Optimization, Product Oversight, Capacity Planning, Mixed-Integer Linear Programming Model, RFID Technology, Optimization Techniques, Resource Utilization Efficiency, Strategic Planning Framework.

I. INTRODUCTION

The pharmaceutical industry encompasses a wide network of processes, activities, and organizations involved in the research, development, and production of medicines and therapeutic products. According to the World Health Organization (WHO), a drug or pharmaceutical preparation is any substance or combination of substances manufactured, sold, or intended for use in diagnosing, treating, mitigating, or preventing disease or abnormal physical conditions in humans or animals, as well as for restoring, correcting, or modifying organic functions.

One of the most critical factors in this sector is time-to-market. During the initial phase of a drug's life—before competing products emerge—pharmaceutical companies earn their highest profits. However, this competition-free window, traditionally lasting between 5 and 12 years, is steadily shrinking. Competitors usually offer similar, though not identical, alternatives. For example, Bayer's cholesterol-lowering drug Baycol was withdrawn in 2001 due to safety concerns, after which competing brands such as Pravachol (BMS) and Lipitor (Pfizer) became top sellers (Butler, 2002; Shah, 2004).

To remain competitive, supply chains in process industries—including manufacturers, suppliers, distributors, and retailers—must demonstrate high levels of efficiency and responsiveness. Achieving "world-class" performance requires well-designed supply networks and optimal allocation of resources across the entire infrastructure. However, the process industry faces numerous challenges arising from inherent factors (e.g., molecular-level process control and diverse asset lifespans) and technical limitations (such as inadequate supply chain analysis tools). Many of these issues stem from past plant and process design decisions influenced by prevailing economic beliefs. As a result, significant improvements often require fundamental changes at the operational and process levels, rather than merely adjusting logistical workflows (Shah, 2005).

The pharmaceutical industry is intensely competitive on a global scale. Increasing demand for affordable healthcare from both individuals and governments has shifted focus toward enhancing production efficiency. Streamlining manufacturing

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operations and upgrading process and product development practices have the potential to significantly improve profitability. Tools such as process simulation and scheduling provide substantial support in this direction (Papavasileiou et al., 2007).

Despite the introduction of many supply chain management strategies, several barriers still limit their widespread adoption. The existing literature contains very few examples from developing countries, and most documented cases emphasize the industry at a macro level rather than individual companies. Addressing this gap, researchers have studied a healthcare organization in Malaysia, identified major operational challenges, and proposed a modern inventory control method to overcome these issues (Mustaffa & Potter, 2009).

The pharmaceutical sector is uniquely complex due to strict regulations and the life-changing nature of its products. Interestingly, preliminary research suggests that supply chain challenges are not always considered among the industry's most pressing issues (Singh, 2005). Historically strong financial performance has reduced incentives to improve supply chain efficiency. The low cost of goods sold (COGS) further encourages companies to rely on excess inventory as a buffer rather than implementing precise and efficient processes. In some countries, such as Pakistan, pharmaceutical business education is limited—while specialized pharmaceutical marketing courses are common internationally, local programs remain scarce and often rely on materials lacking regional relevance (Ahmed et al., 2009).

Globally, the pharmaceutical sector researches, develops, manufactures, and markets medicines intended to cure, immunize, or treat symptoms. By 2020, the industry reached a global value of $1,228.45 billion, with a compound annual growth rate (CAGR) of 1.8%. New technologies, cost-efficient manufacturing practices, and greater investment flows have accelerated the industry's growth. In hospitals, approximately 40% of budgets are allocated to procurement and store operations, much of which is spent on pharmaceuticals. Studies on RFID adoption show that it can significantly improve inventory accuracy and performance (Chong & Chan, 2012).

In developing countries, 60–80% of the population pays for medicines out-of-pocket, and in some regions this number reaches 90%. The pharmaceutical supply chain involves numerous stakeholders, from producers to end consumers (Jetly et al., 2012). Research from Tanzania indicates that receiving near-expired medicines is a leading cause of stock shortages. Across sub-Saharan Africa, poor inventory control—combined with seasonal demand, limited facility access, and logistical constraints—contributes heavily to stock-outs. Common challenges include high losses, improper technology usage, inadequate storage infrastructure, lack of expiration monitoring, distribution problems, and irrational drug use. These issues increase the risk of stock-outs and overstocking, raise out-of-pocket expenses, and tie up financial resources, ultimately reducing the quality of healthcare services.

Managing such complexities is beyond the capacity of any single model or decision level, making a reliable supply of adequate quantities and types of medicines essential for effective healthcare delivery. Improved pharmacy inventory practices help medical facilities balance financial pressures, comply with regulations, maintain proper stock levels, and minimize patient safety risks. Since demand is inherently unpredictable, inventory management remains equally challenging.

Classifying medicines based on their criticality—Vital, Essential, and Normal (VEN)—or cost burden is crucial for effective supply chain operations and cost control. Essential medicines are central to providing basic healthcare services and can save lives. Although essential drugs treat significant but less urgent conditions, they remain necessary for functional health services. In contrast to other industries, supply chain management in healthcare is substantially more complex (Hani et al., 2013).

This discussion focuses specifically on inventory control—quantities, stock levels, and numbers. Although inventory costs do not directly influence manufacturing or procurement costs, they significantly affect a company's overall financial performance. Proper inventory investment can dramatically reduce start-up and operational expenses in pharmaceutical firms. Given that even a small pharmaceutical company may handle over 100 products, inventory decisions carry substantial financial weight.

Studies comparing RFID and barcode systems suggest that RFID offers additional benefits for pharmaceutical inventory control, such as improved tracking, reduced errors, and enhanced visibility (Çakici et al., 2011).

Inventory management is essential across all levels of the pharmaceutical supply chain. Every stakeholder—from manufacturers to retailers—depends on effective inventory practices. For small and start-up companies, however, inventory management is often overlooked. Responsibilities for stock handling frequently fall to undertrained or part-

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time staff, leading to errors that negatively impact sales, growth, and operations. Poor inventory checks can result in severe financial losses and supply inconsistencies.

Inventory management involves ordering, receiving, storing, issuing, and reordering items. Its primary goal is to balance resource limitations with consumer needs while minimizing total inventory costs and maximizing service quality. Research on centralized healthcare networks indicates the importance of evaluating whether logistics operations should be managed internally or outsourced. Studies also highlight the strong correlation between logistics outsourcing, cost reduction, and performance improvement (Azzi et al., 2013).

The pharmaceutical industry is highly globalized. Many raw materials and packaging components originate from the United States and Europe. Due to agreements such as NAFTA, Mexico's pharmaceutical sector is increasingly intertwined with U.S. markets, contributing to heightened competition. Research in this context emphasizes the need to improve the performance of pharmaceutical firms in Mexico. Communication flows—particularly technical information—play a vital role in the supply chain. Since patients rely on physicians to recommend ethical products, pharmaceutical companies must maintain dense, redundant, and timely information channels. These channels operate alongside material flow systems to influence demand and guide product usage (Pedroso & Nakano, 2009).
Given the complexity and critical nature of pharmaceutical operations, the industry must place greater emphasis on robust and efficient inventory management.

II. LITERATURE REVIEW

Inventory in pharmacy operations refers to the stock of medicines maintained to meet patient demand. It is the most significant current asset in a pharmacy, and its value continues to grow with the rising variety and cost of pharmaceutical products. Effective inventory management is essential both financially and operationally, as it helps reduce procurement costs, minimise operating expenses, and increase overall profit (Ayad K. Ali, 2011).
From an organisational perspective, proper procurement, storage, and distribution of medicines are vital for hospitals and pharmaceutical companies. Several researchers have proposed strategies to improve pharmaceutical supply chains. Traditional models used for general inventory often do not work for pharmaceuticals due to factors like high production costs, shelf-life sensitivity, and the serious consequences of shortages or improper usage (Uthayakumar & Priyan, 2013). Therefore, pharmaceutical inventory systems must ensure continuous product availability in the right condition, at the right time, and at the right cost.
As hospitals expand, their need for well-managed pharmacy stores also increases. Expensive and high-volume medications receive priority due to their strong financial and therapeutic impact. Tools like **ABC analysis** help identify high-value items requiring strict control, while **VED analysis** classifies drugs as Vital, Essential, or Desirable based on criticality—helping optimise resource use (Gupta et al., 2007; Singh et al., 2015).
India's pharmaceutical supply chain has also been significantly influenced by COVID-19, especially because the country depends heavily on China for key raw materials. Uncertain supply, delayed deliveries, and panic buying led to price increases and operational challenges (Basha et al., 2020). Hospitals also struggle with issues such as manpower shortages, weak IT systems, limited storage space, and delayed vendor payments (Hani et al., 2020).
To strengthen traceability and reduce risks like theft, counterfeiting, and diversion, many pharmaceutical companies have started adopting **Radio-Frequency Identification (RFID)**. RFID improves visibility across the supply chain, ensures product authentication, and reduces human error. Companies like Pfizer, Merck, GSK, and Johnson & Johnson already use RFID to enhance global monitoring and prevent fraud (Bollampally & Dzever, 2015).
RFID also enables accurate, real-time inventory tracking and reduces shrinkage. Smart RFID-enabled storage systems integrated with Electronic Medical Records (EMR) can ensure safe dispensing by checking allergies, dosage suitability, and patient conditions before issuing medication (Çakici et al., 2011).
Pharmaceutical manufacturing is a high-risk, high-reward sector. Companies must balance manufacturing investment with R&D uncertainty. Optimization-based approaches and **Mixed Integer Linear Programming (MILP)** models help firms make better long-term capacity, production, and profit decisions under uncertainty (Gatica et al., 2001; Levis & Papageorgiou, 2003). These models also support multi-site planning, cost evaluation, and scenario-based analysis.
To remain competitive, the industry must shift from product-centric to customer-centric models. Effective distribution management is essential—ensuring expiry tracking, policy updates, and fast delivery of new products (Lerer & Piper, 2003). Technologies like barcoding, electronic data interchange (EDI), and just-in-time (JIT) systems help reduce costs and improve inventory efficiency (Danas et al., 2002). Outsourcing can also be beneficial if service providers are reliable (Nicholson et al., 2004).
Healthcare supply chains are more complex than other industries. Models like EOQ help public hospitals manage stock levels, but complex decisions often require multi-level, practical frameworks (Kelle et al., 2012). New approaches consider perishable inventory, patient demographics, and stochastic demand patterns (Vila-Parrish et al., 2012).

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Rephrased Summary and Application of Research methods

1. **Optimization-Based Approach**
   Used to determine the optimal production and capacity plan to maximise expected net present value by analysing different demand and success scenarios for each product.
2. **Multi-Stage Planning Model**
   Formulated as a multi-stage stochastic programming model, where decisions evolve over time as uncertainties are resolved.
3. **ABC Analysis**
   Categorises items based on cost significance to prioritise control—especially useful for managing perishable high-value items.
4. **VED Analysis**
   Classifies inventory into Vital, Essential, and Desirable based on criticality and shortage impact, ensuring functional stability.
5. **Ariba Spend Management**
   A procurement tool that enhances supplier-buyer collaboration, improves efficiency, reduces costs, and ensures optimal spending.
6. **Peoplesoft**
   A real-time enterprise system that improves productivity, business performance, and provides cost-effective operational solutions.
7. **Just-In-Time (JIT) Model**
   Receives goods only when needed, reducing holding costs and increasing inventory turnover.
8. **Drop-Shipping Model**
   Enables direct shipment from manufacturer to customer, eliminating warehouse costs and improving efficiency.
9. **Cycle Count Method**
   A structured approach for regular inventory auditing, focusing on order quantity, safety stock, forecasts, seasonality, and replenishment cycles.

III. METHODOLOGY

This section outlines the research methodology used to identify effective inventory management practices in the pharmaceutical industry, particularly in situations where products fail to recover costs due to rapid entry of lower-priced duplicates. The initial search produced nearly 10,000 results, from which approximately 230 relevant articles were selected. The review was focused on the topic, but no restrictions were applied regarding publication dates, resulting in literature spanning from 1995 to 2022.
The first step was the collection of data where the database was identified using certain selected keywords. This literature curation of relevant material including research papers, articles, case studies, publications and reports was acquired from the following database and sources:
Science Direct (https://www.sciencedirect.com/), Google Scholar (https://scholar.google.com/), EBSCO Host (https://www.ebsco.com/products/ebscohost-research-platform), JSTOR (https://www.jstor.org/), Sci-Hub.se (https://sci-hub.se/), ProQuest (https://www.proquest.com/), IEEE Xplore (https://ieeexplore.ieee.org/), IDEAS (https://ideas.repec.org/), Academia (https://www.academia.edu/), Springer (https://link.springer.com/), SAGE Journals (https://journals.sagepub.com/).
The search strategy involved using following keywords in distinct combinations using logical operators (“AND”, “OR”) to identify a network and target publications to conduct the bibliometric analysis.

The 230 selected research papers underwent a two-stage screening process. In the first stage, the abstracts, introductions, keywords, and conclusions were carefully reviewed to assess content relevance and reliability. This initial filtering helped eliminate studies that did not align with the research scope. Articles were excluded for the following reasons:

1. Focused primarily on price trends in the pharmaceutical industry
2. Did not address effective inventory management
3. Emphasized concepts no longer applicable in the current context
4. Discussed general supply chain management rather than pharmaceutical-specific issues

In the second stage, the remaining papers were examined in detail to evaluate their methodology, analysis, applicability, and findings.
All relevant literature was then organized using the Mendeley reference manager, which facilitated systematic citation and bibliography management. Duplicate entries were removed, and the database was exported in Research Information

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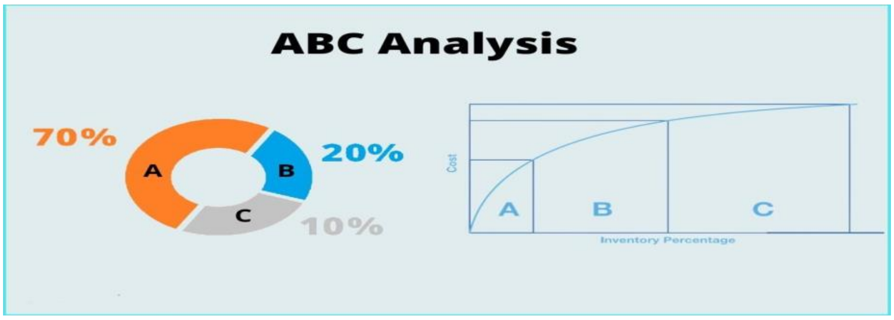
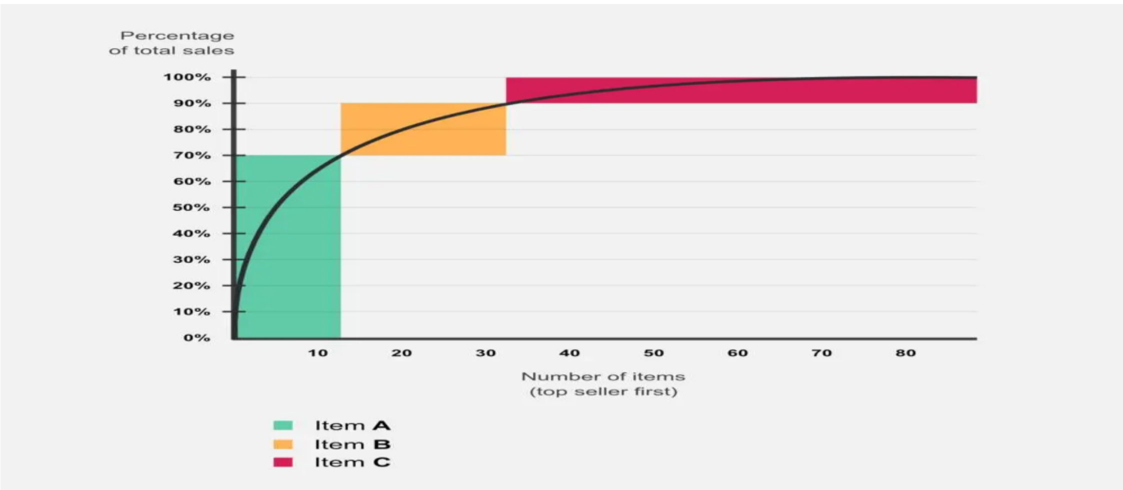
Systems (*.ris) format for bibliometric analysis using tools such as VOS viewer, RStudio, and Word Cloud.
The selected papers were imported into VOS viewer to explore interconnections among the studies and generate visual representations, including maps, graphs, and keyword networks. The resulting bubble diagram highlighted frequently used research methods, with bubble size indicating the level of emphasis in the literature.
Following this, the papers were categorized in Microsoft Excel under four headings— "Article Name," "Publication Year," "Authors," and "Publication Source"— to create charts and tables. This structured data analysis supported insights into the current trends and future directions of the pharmaceutical industry.

ABC Analysis-
Why these help:

- Shows how items are ranked by cost/value.
- Demonstrates cumulative % of cost/usage and how the "A items" dominate.
- For pharmaceuticals, this could map high-value drugs vs low-value items.
- The data charts help you illustrate decision-making (e.g., stricter control for A-items).



Item	Annual number of units sold	Cost per unit	Annual consumption value
Tape measure	50,000	$3.50	$175,000
Carabiner	40,000	$2.00	$80,000
Eyebolt	16,000	$1.50	$24,000
Ferrule	10,000	$1.50	$15,000
Machine screw	21,000	$0.50	$10,500
Flat washer	120,000	$0.05	$6,000
Cable clamp	10,000	$0.50	$5,000
S hook	15,000	$0.25	$3,750
Wing nut	80,000	$0.03	$2,400
Nail	15,000	$0.10	$1,500
Totals	377,000		$323,150



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IV. RESULTS, DISCUSSION, AND EXPERIMENTATION

1. Results of Literature Screening and Analysis

The initial search produced nearly 10,000 results, and through a structured screening process, 230 relevant research papers were shortlisted. The two-stage filtering approach—first based on abstract-level evaluation and later through in-depth reading—helped isolate studies directly addressing inventory management within the pharmaceutical sector. Articles focusing primarily on price evolution, general supply chain concepts, or outdated models were excluded, ensuring that only relevant and methodologically strong literature informed the analysis.

Using tools like Mendeley, VOS viewer, RStudio, and Word Cloud, key themes and frequently used methodologies were identified. The bibliometric analysis revealed that the majority of authors prioritized optimization-based models, analytical planning frameworks, and technology-driven solutions such as RFID, ABC/VED analysis, mixed-integer linear programming (MILP), and Just-In-Time (JIT) inventory methods.

VOS viewer visualizations showed clustering around concepts such as:

- *supply chain optimization*
- *inventory accuracy*
- *capacity planning*
- *technology integration (RFID, barcoding)*
- *stochastic and multi-stage decision models*

The larger bubble sizes indicated that optimization models and technology-enabled inventory tracking were the most dominant research areas.

V. DISCUSSION

The findings reveal that pharmaceutical inventory management differs significantly from traditional inventory systems due to factors such as product perishability, regulatory pressures, risk of stockouts, and the high cost of stock obsolescence. The literature consistently highlights that poor inventory management can lead not only to financial losses but also to severe consequences such as treatment delays, therapeutic failures, and increased morbidity.

Key insights from the review include:

- Technology plays a critical role: RFID, barcoding, and electronic data interfaces greatly improve traceability, reduce errors, and enhance accuracy in pharmaceutical inventory systems.
- Optimization-based models are becoming central: MILP models, stochastic programming, and EOQ-based models help in dealing with uncertainty in demand, lead time fluctuations, and multi-stage decision-making.
- ABC and VED analyses provide practical categorization: These methods allow hospitals and pharmacies to prioritize high-value, high-criticality items and ensure availability of essential medicines.
- External factors such as COVID-19 exposed vulnerabilities: Supply dependencies, shortage of raw materials, and speculative pricing emphasized the need for robust inventory planning and improved visibility across the supply chain.
- Decision Support Systems (DSS) offer a competitive advantage: Companies using DSS can make data-driven decisions regarding procurement, stocking, and replenishment, increasing efficiency and reducing wastage.

Overall, the results demonstrate that an integrated approach combining optimization models, technology, and analytical frameworks is essential for modern pharmaceutical supply chains.

3. Experimentation and Analytical Approach

The experimentation in this research primarily involved bibliometric and qualitative analysis based on the curated dataset of 230 papers.

Step 1: Data Extraction and Preparation

- After screening, relevant articles were exported to *Mendeley* and then converted into. ris format.
- This enabled structured input for tools like VOS viewer and R packages for bibliometric mapping.

Step 2: Bibliometric Mapping (Using VOS viewer and RStudio)

- Keywords were analysed to understand frequency and co-occurrence.
- A bubble network diagram displayed dominant themes, with optimization and RFID technologies being central.
- Co-authorship maps revealed that research activity is concentrated in regions with advanced pharmaceutical industries.

Step 3: Categorization and Visualization (Using Excel)

- Articles were grouped into four categories: *title, year, authors,* and *publication source*.
- Trend graphs indicated a rising focus on RFID adoption and optimization approaches post-2010.

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- Tables summarizing methodologies showed increasing use of multi-stage and stochastic models.

Step 4: Comparative Analysis of Inventory Approaches

- Traditional models like EOQ and JIT were compared with modern approaches such as MILP and RFID-enabled tracking.
- The analysis confirmed that while conventional methods are still useful, technology-enhanced and optimization-based models outperform them in accuracy, responsiveness, and cost efficiency.

VI. CONCLUSION

The pharmaceutical industry is highly specialized and demands effective solutions to streamline production schedules and optimize inventory management. Traditionally, the pharmaceutical supply chain was viewed mainly as a system for ensuring reliable product availability. However, with recent shifts in the operating environment, companies are now reassessing their supply chain components and seeking ways to extract greater value from them.

In this sector, the supply chain extends far beyond the physical transformation and distribution of materials. Efficient supply chain management has become essential for all pharmaceutical companies, with a strong emphasis on optimization. Clear, uninterrupted information flow is critical, leading most organizations to rely on software systems to gather operational data. This data is further enhanced through tools such as Decision Support Systems (DSS), helping companies make informed decisions and gain a competitive advantage.

Optimizing the value chain—from innovation and development through capacity and production planning—is equally important. Despite significant advances, many research challenges remain across the value chain, offering ample opportunities for the process engineering and process systems engineering community to contribute valuable solutions.

The review and analysis clearly indicate that pharmaceutical inventory management is evolving from simple stock control systems to complex, technology-enabled frameworks driven by optimization. The experimentation and bibliometric results highlight that integration of RFID, optimization models, DSS, and systematic analytical tools is crucial for improving accuracy, reducing wastage, and ensuring patient safety. The future of pharmaceutical inventory management lies in digitalization, predictive analytics, and agile supply chain models capable of handling uncertainties such as pandemics and global disruptions.

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